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**PATENT**

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

In re Application of	:	Customer Number: 20277
Masahiro OGAWA	:	Confirmation Number: 6747
Application No.: 10/849,053	:	Group Art Unit: 2826
Filed: May 20, 2004	:	Examiner: MONDT, JOHANNES P.
For: SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME	:	

**ENGLISH TRANSLATION OF JP 2001-345478**

Mail Stop Amendment  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Sir:

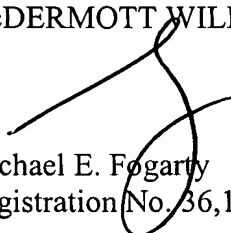
Further to our Response filed on January 3, 2006, we are now submitting a copy of the English translation of JP 2001-345478 which the Examiner requested on Page 2 of the Office Action dated October 3, 2005.

**Application No.: 10/849,053**

To the extent necessary, a petition for an extension of time under 37 C.F.R. 1.136 is hereby made. Please charge any shortage in fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account 500417 and please credit any excess fees to such deposit account.

Respectfully submitted,

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## DECLARATION

I, the undersigned, of 15-29, Tsukamoto, 3-chome, Yodogawa-ku, Osaka 532-0026, JAPAN, hereby certify that I am well acquainted with the English and Japanese languages, that I am an experienced translator for patent matter, and that the attached document is a true English translation of

Japanese Patent Application Laid Open Publication No. 2001-345478A.

I declare that all statements made herein of my own knowledge are true, that all statements on information and belief are believed to be true, and that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Signature:

Natsuko Honjo

Dated: January 12, 2006

[Title of the Invention]

Method for Manufacturing Gallium Nitride Based Compound Semiconductor

[Abstract]

[Object] To improve light emitting efficiency even in the presence of dislocation in a GaN based compound semiconductor.

[Means for Attaining the Object] An n-type AlGaIn layer 12, an undoped AlGaIn layer 16, and a p-type AlGaIn layer 18 are layered on a substrate 10 to obtain a double hetero structure. In forming the undoped AlGaIn layer 16, droplets 14 of Ga or Al are formed on the n-type AlGaIn layer 12. The composition ratio of Ga and Al in the undoped AlGaIn layer 16 varies due to the presence of the droplets 14, creating spatial fluctuation in a band gap. The spatial fluctuation in the band gap increases the percentage of luminous recombination of electrons and holes.

[Claims]

[Claim 1] A method for manufacturing a gallium nitride based compound semiconductor in which a plurality of gallium nitride based compound semiconductor layers are layered on a substrate, comprising the step of:

creating spatial fluctuation in a band gap in at least one of the plurality of gallium nitride based compound semiconductors layers.

[Claim 2] A method for manufacturing a gallium nitride based compound semiconductor according to claim 1, wherein the spatial fluctuation of the band gap is created in such a manner that a composition material of the gallium nitride based compound semiconductor layer is formed discretely in an underlying layer and the gallium nitride based compound semiconductor layer is grown on the underlying layer in which the composition material is formed.

[Claim 3] A method for manufacturing a gallium nitride based compound semiconductor according to claim 1, wherein the spatial fluctuation of the band gap is created in such that a layer for changing a diffusion length of the composition material of the gallium nitride base compound semiconductor layer is formed in the underlying layer and the gallium nitride based compound semiconductor layer is grown on the underlying layer in which the layer is formed.

[Claim 4] A method for manufacturing a gallium nitride based compound semiconductor according to claim 1, wherein the spatial fluctuation of the band gap is created in such a manner that a layer having lattice mismatch is formed in the underlying layer and the gallium nitride based compound semiconductor layer is grown on the underlying layer in which the layer is formed.

[Claim 5] A method for manufacturing a gallium nitride based compound semiconductor according to claim 2, wherein the gallium nitride based compound semiconductor layer is

AlGa<sub>2</sub>N, and the composition material is Ga or Al.

[Claim 6] A method for manufacturing a gallium nitride based compound semiconductor according to claim 3, wherein the gallium nitride based compound semiconductor layer is AlGa<sub>2</sub>N, and the layer is SiN.

[Claim 7] A method for manufacturing a gallium nitride based compound semiconductor according to claim 4, wherein the plurality of gallium nitride based compound semiconductor layers form a superlattice structure.

[Claim 8] A method for manufacturing a gallium nitride based compound semiconductor according to claim 7, wherein the plurality of gallium nitride based compound semiconductor layers are AlGa<sub>2</sub>N and GaN, and the layer having the lattice mismatch is at least any of AlN, InN, AlInGa<sub>2</sub>N, Si, and MgN.

#### [Detailed Description of the Invention]

[Technical Field that the Invention Belongs] The present invention relates to a method for manufacturing a gallium nitride based compound semiconductor and, in particular, relates to an improvement in light emitting efficiency of a light emitting element.

[Prior Art] In recent years, AlGa<sub>2</sub>N and AlGa<sub>2</sub>N/GaN quantum well superlattices (MQW) and the like have come to be known as materials for light emitting elements, particularly as materials for elements emitting light in the ultraviolet band. Typically, these materials are formed on a sapphire substrate, and dislocation of the order of  $10^8$  to  $10^9/\text{cm}^2$  is present due to lattice mismatch.

[Problems that the Invention is to Solve] At a dislocation point, an electron and a hole, which are carriers, recombine without emitting light (non-luminous recombination). Because of this, as the dislocation density increases, the light emitting efficiency of a light emitting element decreases in general.

FIG. 4 schematically shows the band gap  $E_g$  of a material for a light emitting element. As shown in the figure, when there is spatial fluctuation in the band gap of the light emitting element material, light emission occurs only at the region where the band gap is narrow (gap "a" in the figure). Therefore, if the density of the light emitting points present due to the spatial fluctuation in the band gap could be set higher than the density of dislocation in the light emitting element material, it would be possible to obtain a percentage of the luminous recombination occurring at the region where the band gap is narrow which is higher than the percentage of the non-luminous recombination of electrons and holes at the dislocation points (gap "b" in the figure), and, therefore, lowering in light emitting efficiency can be inhibited.

The object of the present invention is to provide a manufacturing method that enhances

the characteristics such as light emitting efficiency and the like even in the presence of dislocation in a gallium nitride based compound semiconductor such as GaN, AlGa<sub>N</sub>, and the like.

[Means of Solving the Problems] In order to achieve the above objects, there is provided, according to one aspect of the present invention, a method for manufacturing a gallium nitride based compound semiconductor in which a plurality of gallium nitride based compound semiconductor layers are layered on a substrate, comprising the step of: creating spatial fluctuation in a band gap in at least one of the plurality of gallium nitride based compound semiconductor layers. The spatial fluctuation is created in the band gap to cause recombination of the carriers in the region where the band gap is narrow, thereby increasing the light emitting efficiency regardless of the presence of dislocation. It is preferable that the spatial fluctuation in the band gap be created at a density higher than the dislocation density. For example, if the dislocation density is  $10^8$  to  $10^9/\text{cm}^2$ , it is preferable that the spatial fluctuation be created so that the average distance between light emitting points (the region where the band gap is narrow) is 1  $\mu\text{m}$  or less.

According to another aspect of the present invention, the spatial fluctuation of the band gap is created in such a manner that a composition material of the gallium nitride based compound semiconductor layer is formed discretely in an underlying layer and the gallium nitride based compound semiconductor layer is grown on the underlying layer in which the composition material is formed. In the presence of the composition material in the underlying layer, the solid phase composition of the composition material increases in forming the GaN based compound semiconductor layer on the underlying layer to cause difference in composition ratio from the part where the composition material is absent. The difference in composition ratio creates the spatial fluctuation in the band gap. The composition material of the GaN based compound semiconductor layer is any of Al, Ga, and N in the case of AlGa<sub>N</sub> and is any of In, Ga, and N in the case of InGa<sub>N</sub>. Adjustment of the density of the discretely formed composition material attains adjustment of the period (or density) of the spatial fluctuation of the band gap.

According to still another aspect of the present invention, the spatial fluctuation of the band gap is created in such that a layer for changing a diffusion length of the composition material of the gallium nitride base compound semiconductor layer is formed in the underlying layer and the gallium nitride based compound semiconductor layer is grown on the underlying layer in which the layer is formed. The presence of the layer for changing the diffusion length of the composition material in the underlying layer causes composition variation between the compositions of the GaN based compound semiconductor layer owing to the change in diffusion

length when the GaN based compound semiconductor is formed on the underlying layer. This composition variation creates the spatial fluctuation in the band gap. Adjustment of the density of the layer for changing the diffusion length of the composition material attains adjustment of the period (or density) of the spatial fluctuation of the band gap.

According to yet another aspect of the present invention, the spatial fluctuation of the band gap is created in such a manner that a layer having lattice mismatch is formed in the underlying layer and the gallium nitride based compound semiconductor layer is grown on the underlying layer in which the layer is formed. In the presence of the lattice mismatch in the underlying layer, the thickness of corresponding part of the GaN based compound semiconductor layer formed on the underlying layer becomes different from (thinner than) the thickness of the other part. The thickness variation causes spatial fluctuation in the band gap. In the case where the GaN based compound semiconductor has a quantum well structure, for example, the spatial fluctuation of the band gap is remarkable.

[Embodiment of the Invention] Preferred embodiments of the present invention will now be described with reference to the drawings.

FIG. 1 shows a method for manufacturing a gallium nitride based compound semiconductor according to the present embodiment. In the present embodiment, a light emitting element having a three-layer double hetero structure of n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$ /undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ /p-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  is manufactured.

First, as shown in FIG. 1(A), an n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer 12 is grown on a substrate 10 of, for example, sapphire at a temperature of 1050 °C. Then, trimethyl gallium and nitrogen gas are supplied to the substrate for a few seconds at a temperature of 800 to 1050 °C, to thereby form gallium droplets 14 having a diameter of approximately 10 to 500 nm discretely on the n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer 12 by MOCVD.

Then, as shown in FIG. 1(B), an undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16 is grown at a temperature of 1050 °C on the n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer 12 on which the Ga droplets (or micro-blocks of gallium) 14 are formed. Here, in the region where Ga droplets are present, the solid phase composition of gallium within the undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16 becomes high, and thus, spatial fluctuation is created in the band gap of the undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16. In FIG. 1(B), this phenomenon of composition variation within the undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16 in the presence of the gallium droplets 14 is schematically shown by different hatchings. The undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16 can have, for example, a thickness of 0.05  $\mu\text{m}$ . Such composition variation causes spatial fluctuation in the band gap, that is, widening and narrowing of the band gap. After the undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16 in which the spatial fluctuation is created in the bad gap is grown, a

p-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer 18 is grown at a temperature of 1050 °C to attain a double hetero structure. The growth of the aforementioned semiconductor layers can be performed by placing the substrate onto a susceptor of a reaction tube and sequentially introducing the material gases into the reaction tube while heating the substrate 10 by a heater.

The present inventors have confirmed that when voltage is applied to a double hetero type light emitting element obtained as described above so that light is emitted, the illumination intensity is approximately 10 times the illumination intensity in a structure with no Ga droplets 14 formed.

In the present embodiment, Ga is used as the material for the droplets 14, but either Al or Ga, which are both composition materials of the  $\text{AlGaIn}$ , can be used. For example, droplets of Al can be formed by flowing trimethyl aluminum onto the heated substrate 10, in place of trimethyl gallium.

FIG. 2 shows a manufacturing method according to another embodiment. In this embodiment, a light emitting element having a three-layer double hetero structure of  $\text{AlGaIn}$  is manufactured, similar to FIG. 1.

First, as shown in FIG. 2(A), an n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer 12 is grown on a substrate 10 at a temperature of 1050 °C, and an  $\text{SiN}$  layer 15 is formed discretely on the surface of the n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer 12. The  $\text{SiN}$  layer 15 may be formed discretely in such a manner that an  $\text{SiN}$  layer is formed first on the entire surface and then part of the  $\text{SiN}$  layer is removed. Alternately, the  $\text{SiN}$  layer 15 may be formed by adjusting the flow rates of silane gas and ammonia gas, which are material gases for  $\text{SiN}$ . The region where the  $\text{SiN}$  layer 15 is formed becomes a mask section and the region where the  $\text{SiN}$  layer 15 is not formed becomes a window section.

Next, as shown in FIG. 2(B), an undoped  $\text{AlGaIn}$  layer 16 is grown on the n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer 12 on which the  $\text{SiN}$  layer 15 is formed. Here, the growth begins at the window section where the  $\text{SiN}$  layer 15 is not formed and progresses on the  $\text{SiN}$  layer 15. When the undoped  $\text{AlGaIn}$  layer 16 is grown on the  $\text{SiN}$  layer 15, the compositions of Al and Ga within the undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16 becomes different between the window section and the mask section because the diffusion lengths of the Ga atom and the Al atom on  $\text{SiN}$  are different. More specifically, because Al is absorbed in the solid and does not migrate on  $\text{SiN}$  as much as does Ga, the Al composition at the window section is relatively small. As the Al composition decreases, the band gap becomes narrower (smaller), with a result that spatial fluctuation is created in the band gap of the undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16. After the undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer 16 in which spatial fluctuation is created in the band gap is grown, a p-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer 18 is grown to obtain a double hetero structure.

In the present embodiment, as in the previous embodiment, the spatial fluctuation of the band gap can easily be created at a density equal to or greater than the dislocation density, and thus, the light emitting efficiency can be improved.

FIG. 3 shows a manufacturing method according to still another embodiment. In this embodiment, a light emitting element having an AlGaIn/GaN quantum well superlattice (MQW) structure is manufactured.

An AlGaIn layer 20 is formed on a substrate (not shown), and then, a GaN layer 22 is formed. These layers are formed repeatedly by the same manner at  $n$  pitch ( $n$  can be set, for example, as 20) to obtain a superlattice structure. The thickness of each layer can be set at 1 to 100 nm, for example, approximately 5 nm. The GaN layer 22 is formed on the AlGaIn layer 20 in such a manner that a layer (lattice mismatch layer) 21 of a material having relatively large lattice mismatch, more specifically, AlN, InN, AlInGaIn, Si, MgN, or the like is formed discretely and the GaN layer 22 is formed on the AlGaIn layer 20 on which this layer 21 is formed. Each of the layers including the layer 21 can be formed by MOCVD, as in the aforementioned two embodiments. If there is a substance having large lattice mismatch at the interface of a superlattice, minute roughness is generated in the surface portion. Because the thickness of the GaN layer 22 at the rough part differs from that of the other part, the thickness of the layer becomes uneven. Due to this unevenness, the quantum level based on the quantum effect varies spatially to cause fluctuation in the band gap spatially. By forming the layer 21 having a density sufficient to set the density of the spatial fluctuation in the band gap to be equal to or greater than the dislocation density, the light emitting efficiency can be improved.

The present inventors have confirmed that when voltage is applied to a light emitting element having a superlattice structure as shown in FIG. 3 (using AlN as the layer 21) so that light is emitted, a light emission intensity of 10 times that produced when the layer 21 is not formed can be achieved.

While the illustrative embodiments of the present invention have been described, the present invention is not limited to these embodiments and various modifications can be made within the scope of the technical idea of the invention. For example, in FIG. 2, a material other than SiN, for example, SiO<sub>2</sub>, can be used as a material for the layer for changing the diffusion length of the composition of AlGaIn.

Also, although FIG. 3 shows a lattice mismatch layer 21 formed on the AlGaIn layer 20, it is also possible to form the lattice mismatch layer 21 on the GaN layer 22 for forming spatial fluctuation in the band gap of the AlGaIn layer 20.

Furthermore, although FIG. 3 shows an example employing an AlGaIn/GaN MQW

structure, the MQW can be constructed from other materials. For example, the MQW structure may be preferably formed from AlGaN/AlN/GaN. In this case, the lattice mismatch layer 21 can be formed at the interface between AlGaN and AlN and the interface between AlN and GaN.

[Effects of the Invention] According to the present invention, the spatial fluctuation of the band gap in the GaN based compound semiconductor can be created easily, thereby improving the characteristics such as light emitting efficiency.

[Brief Description of the Drawings]

[FIG. 1] FIG. 1 includes explanatory diagrams showing a manufacturing method according to an embodiment.

[FIG. 2] FIG. 2 includes explanatory diagrams showing a manufacturing method according to another embodiment.

[FIG. 3] FIG. 3 is an explanatory diagram showing a manufacturing method according to still another embodiment.

[FIG. 4] FIG. 4 is an explanatory diagram illustrating spatial fluctuation of a band gap.

[Explanation of Reference Numerals]

10: substrate, 12: n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  layer, 14: Ga droplet, 15: SiN layer, 16 undoped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  layer, 18: p-type AlGaN layer, 21: lattice mismatch layer

FIG.1 (A)

Substrate

FIG. 1(B)

Substrate

FIG. 2(A)

Substrate

FIG. 2(B)

Substrate